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Tekties - the age paradox controversy revisited

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Abstract

The australite age paradox controversy of the 1970's is revisited in the light of recent developments in our knowledge of tektites. Important new discoveries in the North American and other strewn fields provide strong, but indirect evidence against the very young (<20 000 years) age of arrival for australites to the Australian continent proposed by Baker (1959, 1962), Gill (1970) and Lovering *et al.* (1972, 1979). Though the evidence from the Lake Torrens region of South Australia presented by these authors at the time was extremely convincing, the evidence from outside Australia is such that to accept this young age of arrival seems to require acceptance of an impossible set of corollaries. The 0.77 myr radiometric age of the tektites must, it is believed, be the age of return to Earth of the terrestrial-sourced australites, though this implies a "dark age" in the geological history of the tektites of which we have no knowledge and also extraordinary preservation through three quarters of a million years of some almost pristine ablated flanged forms in four regions of Australia. Microtektites are found in deep-sea sediments offshore from Australia of the radiometric age and none are found of the suggested younger age. It is suggested that direct evidence of tektites or microtektites within older Pleistocene formations might be revealed in hidden sections of unconsolidated sediments beneath the large saline claypan lakes south of Kalgoorlie (though the technical difficulties of studying such sections are immense, and the Pleistocene representation there appears to be thin). Direct evidence supporting the radiometric age has lately come from the Bow River area in the north of Western Australia and from a re-examination of the stratigraphy near Port Campbell, Victoria. It seems likely that ablated tektites, those which have exited from and re-entered the Earth's atmosphere, are restricted to the distal part of the Australasian strewn field, south of a boundary line running just north of Java.

Introduction

A recent review of the global occurrence of tektites (McCall 1997) concluded that the two outstanding unsolved enigmas of Australasian tektite origins are (1) the source of the Australasian strewn field, and (2) a satisfactory explanation for the layered and irregular Muong Nong tektites. Dr Brian Mason (personal written communication) does not dispute the two enigmas (McCall 1997), but adds two further enigmas, which relate to the arguments set forth by Baker (1959, 1962), Gill (1970) and Lovering *et al.* (1972), which were supported by Chalmers *et al.* (1976), vigorously disputed by Glass (1978), restated again by Chalmers *et al.* (1979) and finally countered by Glass (1979) in a reply. Mason wrote in his communication to the author

"...there are two enigmas:

1) the age paradox: most australite investigators, myself included, believe their terrestrial age is around 10 000 years (5 000).

2) Why has no one found micrometeorites on land in Australia (many thousands of soil samples have been examined)?"

(Mason, personal communication).

This retention of the "age paradox" is surprising because, after an exhaustive study of the literature, McCall (1997) had come to assume rightly or wrongly that it was no longer tenable, and that most workers on tektites accepted this. It seems that, 20 years later, there is a case for reconsidering the problem, which provides an interesting illustration of the philosophy involved in a scientific controversy in which there is an apparently irresolvable conflict of evidence. New indirect evidence bearing on the controversy has accrued in the intervening years, and lately some new direct evidence has come to light in Australia.

The fundamental concern of the age paradox was the fact that the apparent stratigraphic ages of australites (that is the age of the formations in or on which they are found) are nowhere near as great as the radiometric ages (K-Ar, Ar-Ar, fission track) determined for them and which are widely taken to give the age of fall to Earth (such values actually relate to the solidification of the tektite glass, but in terms of the Geological Time Scale the separation of this from the time of fall to Earth is infinitessimal). Whereas stratigraphic ages range from about 20 000 years, down to 6 000 years and even younger, the radiometric age determined on tektites throughout the entire Australasian strewn field is widely taken to be 0.77 million years (Izett & Obradovich 1992). This age is also widely accepted for microtektites from the ocean adjacent to Australia, because it is established by their presence just prior to the the Brunhes-Matuyama reversal boundary (Glass & Wu 1993), which is placed at 0.78-0.79 million years ago, on the basis of Ar/Ar dating of extrusive rocks which bracket it (Fudali 1993).

It should be noted here that Bottomley & Koeberl (1999) have recently published results of research that indicates that there may be two tektite strewn fields, an Australasian one and another smaller Australian one of greater age (about 10 million years). Interestingly, most of the high soda australites which have yielded this higher radiometric age come from the NW quarter of South Australia, not very far from the Lake Torrens area, where the very young australites have been postulated by Lovering *et al.* (1972). This new discovery means that there is now an absolute "age paradox" of a different nature, complicating the picture, but this development has no bearing on the problem discussed in this text.

Stratigraphic age

Australia

Australia lies at the southern (distal to source) end of the largest known tektite strewn field (the Australasian strewn field; Fig 1). The evidence of the stratigraphic age of australites in Victoria and Western Australia is not precise (Baker 1959; Barnes 1963). At Port Campbell, Victoria, tektites are definitely younger than the Miocene limestones, but "do not occur in the nearby post-Pliocene dune limestone of the district, and are therefore post-Pliocene" (Baker 1959). This poses the question, what is the exact age of the dune limestone? It also poses the question whether non-occurrence in a formation proves that the date of fall was younger than that formation. Processes of accumulation in terrestrial sediments are very complex and not every formation deposited after the arrival of a tektite shower can be expected to contain them in sufficient quantity to be detected; some may not contain them at all. The tektites were said by Baker (1959) to occur at Port Campbell partially buried in post-Miocene superficial clays and surface soil, and he added "their occurrence in surface soils indicates a still younger geological age for some specimens", but this does not seem to have any bearing on the age of fall; it only indicates reworking from older formations.

Fudali (1993) re-examined the evidence from Port Campbell, as well as sites nearby at Stanhope Bay and inland. The field evidence differs from that given by Baker (1959); he relates the tektite concentration to a sandstone layer with buckshot gravel, whereas Baker (1959) described them as buried in superficial clays and surface soils. Nevertheless, Fudali (1993) made some important observations.

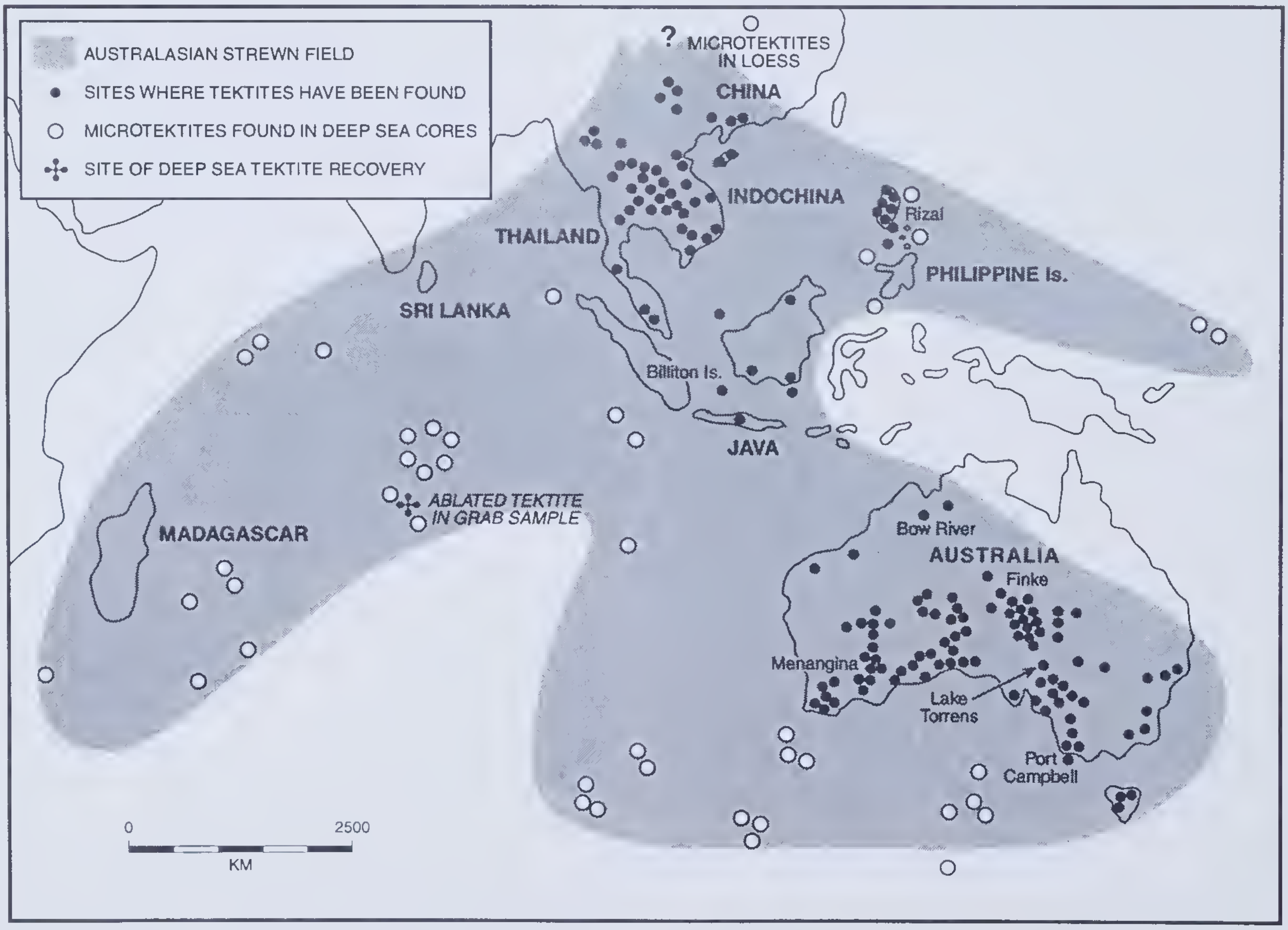

Figure 1. The Australasian strewn field (slightly modified from the figure presented in McCall 1997).

1) At Stanhope Bay, the tektites were described by Gill (1970) as resting on recent sand-dunes, where they had either fallen directly or been carried by Aborigines. Fudali (1993) observed that they are all water-worn and thus must have undergone natural transport to where they now were found; they could not, therefore, be at the site of fall.

2) The tektites recovered from a 256 m^2 patch of ground near Port Campbell by archeological-type digging (excavating down to the 'hardpan') were all fragments, and mostly derived from flanges of ablated tektites; they could not in any way be fitted together nor make up whole tektites by such assemblage, and the conclusion of Fudali (1993) was that they were sorted by size or shape, during transport.

3) A few tektites from Port Campbell were found embedded in the aeolian sandstone beneath the tektite rich layer. Fudali (1993) demonstrated that they had not fallen into cracks from above, as had been previously suggested, but were actually within the rock. This aeolianite has not been accurately dated, but is generally regarded as Pleistocene. It is not absolutely clear from Fudali's account which rock this is, but it seems that the "dune limestone' of Baker (1959) is the 'sandstone aeolianite' of Fudali (1993).

Fudali's (1993) succinct conclusion is that the proposed 5 000 yr (Baker 1959) to 15 000 yr (Gill 1970) maximum age of fall is demonstrably incorrect and that the australites are found in a formation older than those described by the above authors. Fudali (1993) also used cosmogenic radionuclide data to support this contention.

We will return to the almost pristine preservation of flanged forms at Port Campbell later, and even more recent investigations there. Both Baker's (1959) assertion that the tektites must have fallen no more than *ca* 5 000 years ago and Gill's (1970) figure of 15 000 yr, based on a radiocarbon date on the middle of the 'hardpan', do not seem to rely on anything but the excellent preservation of some of the australites, which is not disputed. Though Fudali (1993) regarded these Port Campbell australites as "unique among all known australites... most being unmarked by mechanical abrasion and showing only very minor chemical etching", equally perfect forms have been recorded by the late W H Cleverly (1988, 1994) from Gindalbie and Menangina Pastoral Stations (Western Australia) and Finke (Northern Territory). Port Campbell australites are remarkable, but by no means unique.

In Western Australia, tektites are mainly recovered from the surface of saline playa lakes. They tend to resist the corrosive effect of the salt, but are commonly mechanically abraded, although excellent flanged forms comprise a minority of such recoveries. These lake surfaces are present-day saline claypan surfaces and, whereas tektites are found on and in superficial deposits widely over the State, there has been no systematic study of derivation of tektites from within dated sedimentary formations and indeed such a study might be tediously difficult (given the abundance of laterites, silcretes *etc*), though any evidence of tektite recoveries from within such sediments would be critical to this discussion. Perhaps the best chance of finding tektites in older, datable (Pleistocene) sediments associated with these lakes lies in the thick sections of unconsolidated sediments beneath the surficial clays of the large lakes between Kalgoorlie and Norseman, but the chance of finding a tektite within a small diameter core recovery is very small, and the Pleistocene representation is reportedly thin. Microtektites could, however, conceivably be found in cores of these sediments, if they have not been dissolved by the saline waters.

Recently, however, discoveries of tektites within sediments have been described from the Bow River area of the extreme north of Western Australia (Fudali *et al.* 1991; Fudali 1993). Tektites are rarely found on the surface here; the much higher rainfall than in the remainder of the State apparently washes them into sedimentary deposits. These finds are in diamondiferous gravels and Fudali (1993) cited ^{3}He isotope determinations of cosmic-ray exposure age for the diamonds to indicate an age of at least 250 000 years for these deposits. The method used has some uncertainties and cannot be used to fix a precise age for the diamondiferous gravels, but it does seem to preclude the very young ages for the tektites suggested by Baker (1959, 1962), Gill (1970) and Lovering *et al.* (1972).

Only in the Lake Torrens area of South Australia has detailed sedimentological evidence of tektite recoveries and their absence from dated sediments been gathered (Lovering *et al.* 1972) and this work really provides the crux of the argument for a fall age of no more than 24 000-16 000 years. Australites are recovered from interdune corridors, floored by clayey sand dated at *ca* 6 000 yr (Holocene), also from modern sand dunes, and the Motpena palaeosol (*ca* 12 000 years old), Lovering *et al.* 1972 considered the relict seif dunes of the Lake Torrens formation (24 000-16 000 yr) to be the "ultimate source" of the tektites Good flanged button forms are illustrated, but the surfaces are quite pitted and they have clearly suffered some terrestrial degradation.

The basic stratigraphic relationships as far as they are known were known at Port Campbell, Lake Torrens and Western Australia, when the "age paradox" was proposed, are summarised in Fig 2. At Port Campbell, tektites are found in recent soils and superficial clays, buckshot gravel and, rarely, in the aeolianite below. In the Lake Torrens area, they are found in or on three ages of formation, a modern dune sand and an older palaeosol, as well as a clayey Holocene sand in the corridors, and are believed to have an "ultimate source" in the older Torrens relict seif dunes (of Wisconsin age, no more than 24 000 yr). There is clear evidence that they occur in deposits of several ages. In the southern part of Western Australia, they are found on active saline clay pan lakes and around their fringes, also in or on superficial deposits away from the lakes. They have clearly been washed in onto the lake surfaces of clay or salt, but there is little or no evidence as to the nature of the older source formations from which they have come. Tektites are also found in diamondiferous gravels in the north of the State, and there is reason here to believe that the host sediments are at least 250 000 years old (but this discovery postdated the original controversy by more than a decade).

Only for the Lake Torrens area, other than reliance on the good state of preservation of flanged australites, have

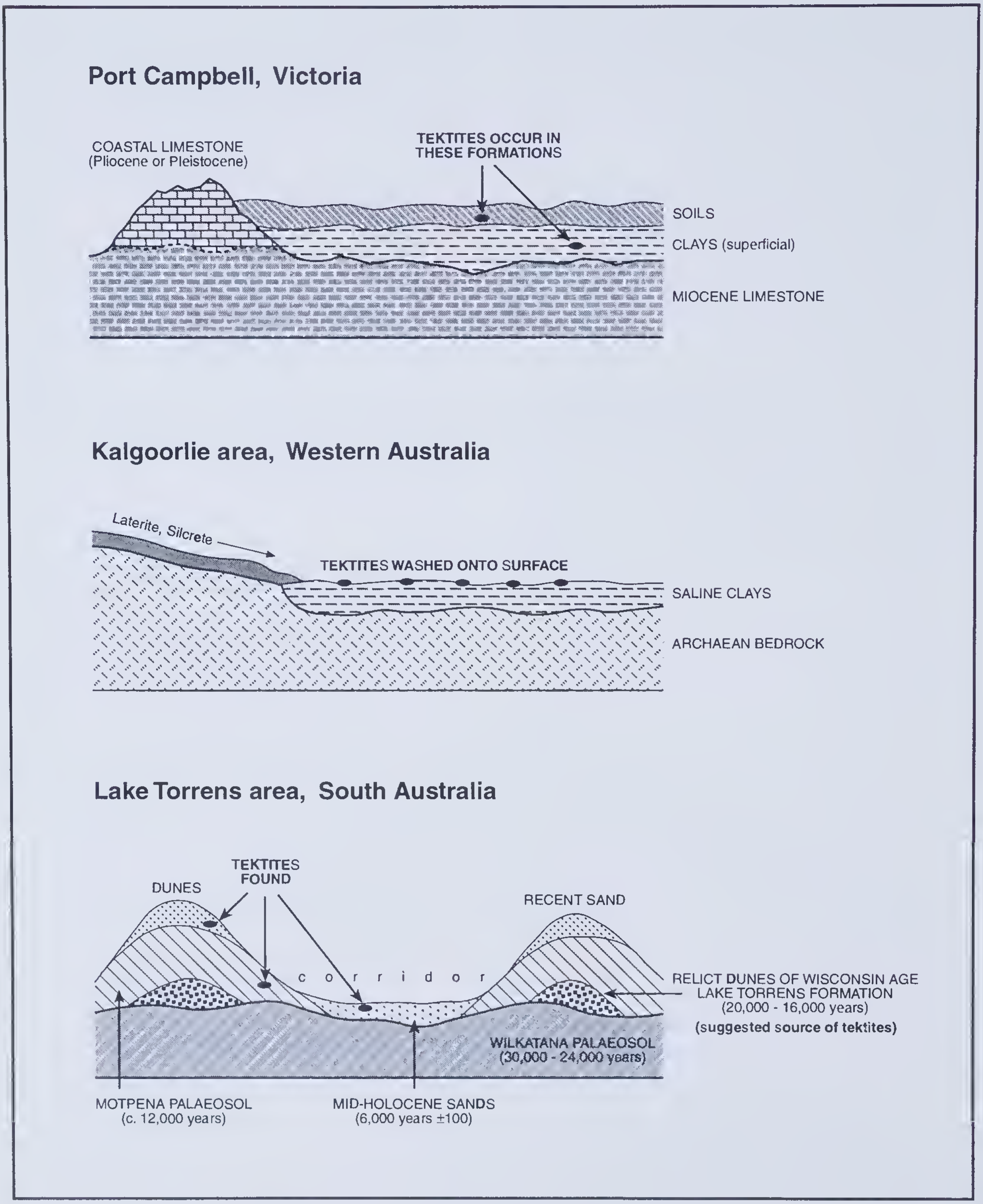

Figure 2. Schematic drawing illustrating the essential relationships at Port Campbell, Victoria (following Baker 1962), Lake Torrens, South Australia (following Lovering *et al.* 1971) and in Western Australia (Kalgoorlie region).

arguments been advanced for the tektites having not been transported any distance and being recovered close to where they fell. Besides citing the state of preservation of the australites at Motpena and Myrtle Springs, it was noted by Chalmers *et al.* (1979) that the nearest possible older source formation is 25 km northward of the find sites and transport by vigorous streamfloods thence could not, they believed, have been undergone by the delicate forms preserved. In addition, it was argued that the Lake Torrens region is a tectonic depression which has been sinking throughout Holocene times, so a 770 000 year old horizon will be deeply buried and inaccessible to erosion. Localisation of specific gravity groups and geochemical groups to different find sites also was taken to indicate that individual find sites correspond to fall sites closely, otherwise such groupings would have been lost by transport and reworking.

As in the case of Western Australia, new evidence has emerged regarding the Lake Torrens occurrences. Shoemaker & Shoemaker (1997) looked again at the dunes there and observed an invariable association of australites with stones of like dimensions, the latter vastly outnumbering the tektites (they suggested a proportion of 10 000 stones to one australite). Transport by Aborigines was suggested to explain the movement of some of the stones and the tektites onto the dunes, but the high ratio observed suggests that some natural agency may have been involved rather than a human agency. A possible agent is the very common dust-devil whirl-winds (or "Cock-eyed Bobs") that are common in the hot, dry interior of Australia. Might innumerable repetions of such miniature tornados, over long periods, be capable of taking up into the air and redepositing stones and tektites?

No recovery of microtektites on land in Australia

The author does not find the absence of recovery of microtektites on land in Australia to be a very strong argument for a young age of fall; in deep sea cores concentrations of microtektites are found in sediments of the same age as the radiometric age of the tektites in the Australasian strewn field. Such fine material might be found concentrated in sediments *of the same age* on land; but, the author is not sure that any search has been made of sections through sediments of that age in Australia. However, if the older radiometrically-determined fall age is correct for the Australasian strewn field, then it is extremely unlikely that they could be found in superficial soils, as Glass (1979) concludes in his reply. On land, the dissolution rate of tektite glass is second order of magnitude larger than in the ocean; it has been shown that on land the dissolution rate of tektite glass is a much higher than in seawater, where magnesium appears to act as a buffer (C Koeberl, Universität Wien, personal communication). The absence of microtektites from such deposits appears to be in no way inconsistent with the 0.77 Ma radiometrically-derived fall date. Mason's second enigma above does not appear to be valid.

In addition, Glass & Wu (1992), from a study of deep-sea cores, showed that there was no microtektite productivity event in the ocean around Australia *ca* 20 000 years ago, or less.

Evidence from other strewn fields

North American strewn field

The age paradox is not peculiar to Australia. It was for a long time also suggested in the much older North American Strewn Field (Fig 3), where Texas bediasites are found in gravels above and much younger than late

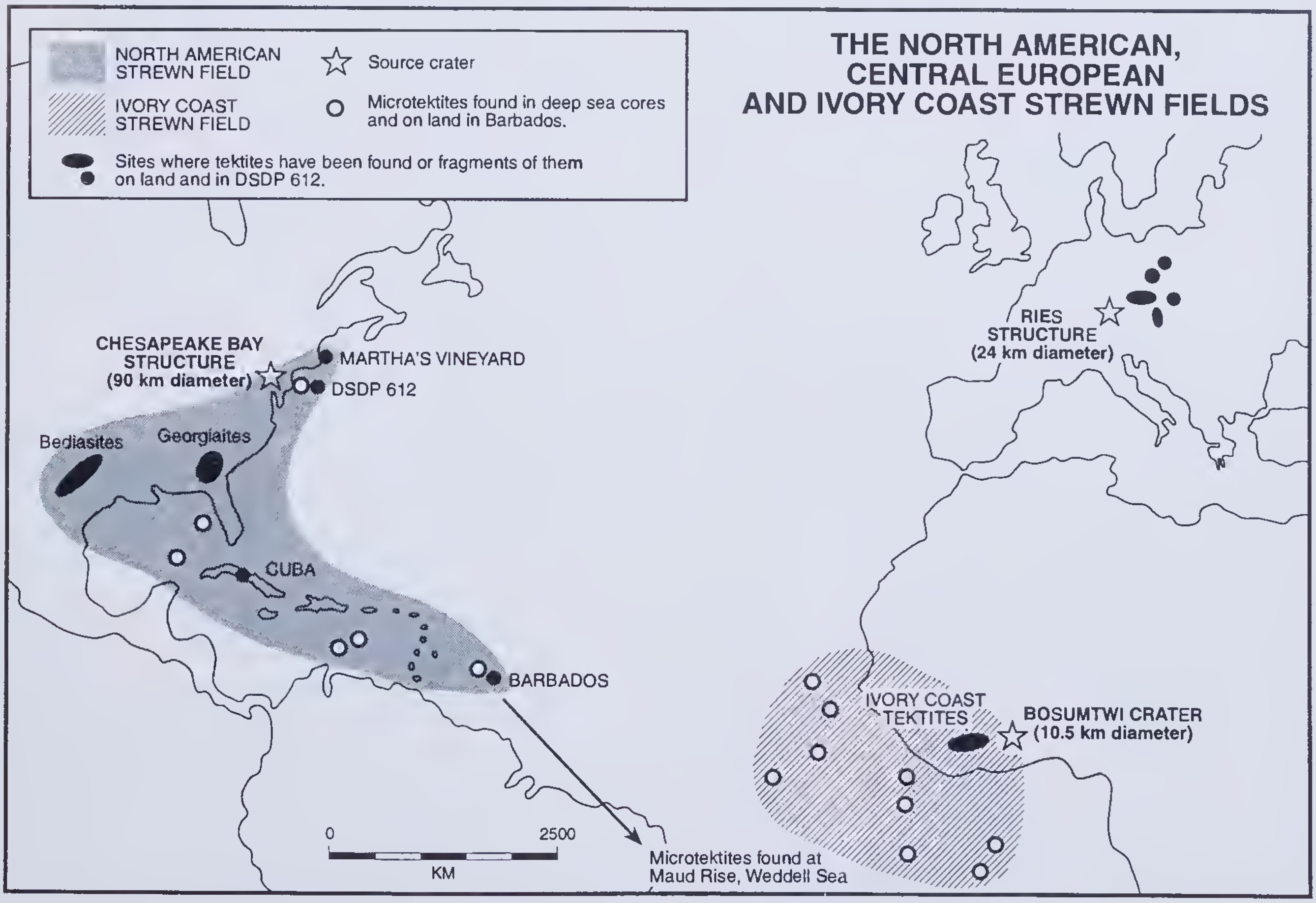

Figure 3. The North American, Ivory Coast and Central European Strewn Fields (slightly modified from McCall 1997).

Eocene rocks, and georgiaites are found in gravels above Miocene rocks, that the stratigraphic age was much less than the radiometric age; 34-35 Ma, equivalent to the very top of the Eocene. However this paradox disappeared with the discovery of tektite fragments and microtektites together in core at DSDP 612 of the New Jersey Coast (Glass 1989) and in sediments on land at Barbados (Sanfilippo *et al.* 1985; Koeberl & Glass 1988). In both localities the stratigraphic age of the containing sediments and the radiometric age of the North American tektites almost exactly matched. A 90 km diameter structure in Chesapeake Bay was also found to be of the same age, *ca* 35.5 Ma, and deemed to be the source of the strewn field (Koeberl *et al.* 1996).

There are a number of further points to make about this strewn field. The tektites, inevitably much corroded and abraded because of their greater age on Earth than those of the Australasian strewn field, only occur in certain formations where they have presumably been concentrated by some terrestrial agency. Many underlying, intervening, and younger formations within the limits of the strewn field must be devoid of them at least in such quantities as to be recognisable (this makes the point again that not finding them in a formation does not mean that the formation is older then the date of fall). Having said this, the time scale is quite different to the maximum possible scale from fall (as indicated by radiometric ages) to present day in Australia, being very much greater (34.5 as against 0.77 Ma), so these tektites have inevitably a much longer potential history of recycling. The evidence from the North American strewn field provides overwhelming support for the validity of radiometric ages as true indicators of the age of fall back to Earth. This strewn field also includes associations of microtektites recovered with fragments of tektites of the same composition (in DSDP 612 and at Barbados), which seems to dispel doubts expressed whether the microtektites are related to tektites in the Australasian strewn field. As far as the author knows, only a single aerodynamically ablated form has been described from the North American Strewn field.

Ivory Coast strewn field

Here (Fig 3) the tektites occur in superficial gold-bearing alluvial deposits close to the surface, and of quite recent age. The microtektites offshore from West Africa have a stratigraphical age constrained by the closeness of the microtektite bearing layer to the Jaramillo geomagnetic event (0.97 Ma; Glass *et al.* 1991); the tektites are believed to have fallen just after the beginning of the Jaramillo event. This, within the limits of error, is consistent with both the radiometric age of the tektites (1.07 Ma preferred age) and the age of the widely accepted source structure, the Bosumtwi crater in Ashanti (impact glass, fission track age 1.03 ± 11 Ma: Koeberl *et al.* 1997). Reliable radiometric ages cannot, unfortunately, be obtained for the microtektites, though two fission track determinations average to about the same figure (Koeberl *et al.* 1997). Here, as in Australia, the tektites occur in very recent but undated deposits and there is a time gap between the likely age of these and the radiometric age. Unfortunately, virtually no modern study has been made of the stratigraphy of the tektite bearing formation and only some 200 tektites have so far been recovered on land (McNamara & Bevan 1991). There are no aerodynamically-shaped flanged tektites.

Central European strewn field

The widely accepted source of this strewn field (Fig 3) is the Nördlinger Ries structure in southern Germany, dated by K/Ar and fission track methods at 15.1 ± 0.1 Ma (Staudacher *et al.* 1962) The tektites are found in gravels of the Helvetian stage (an obsolete term, modern equivalent Lower Vindobonian) of the Miocene of Moravia (Barnes 1963), which is quite consistent with a radiometric age of 15.1 ± 0.1 Ma also determined, on a moldavite tektite (Staudacher *et al.* 1982). Koeberl *et al.* (1988) reported moldavites from gravels of probable Miocene age in Austria, from Oligocene to Lower Miocene sediments in Bohemia and from Pliocene sediments in Moravia. They have clearly been reworked. There are no marine recoveries of microtektites from this strewn field, though they could well occur in the Baltic Sea (tektites have been recovered near Dresden). Microtektites have been recorded from 'molasse', Post-Alpine continental deposits, in Bavaria (Storzer & Gentner 1970), but these have been shown to be microscopic bodies of volcanic origin (Graup *et al.* 1981). There seems to be no age paradox in this strewn field. Again, there appears to be only a single record of an aerodynamically ablated form.

Inferences from outside the Australasian strewn field

The fact that all these three strewn fields do not now, since the recent discovery of the Chesapeake structure and the DSDP 612 and Barbados tektite occurrences, have any discrepancy beween radiometric age and age of the widely accepted source structures, and that in two out of three the greatest known stratigraphic age is compatible with radiometric age and that of the source structure, would seem to militate strongly for the radiometric age of tektites indeed indicating the age of fall *i.e* return to Earth. The difference in time between ejection from the source crater and fall to Earth again can have been no more than hours in the case of any of the known tektite strewn fields, as there is no evidence of complete Earth orbits. There is also conclusive evidence that tektites and microtektites are very closely related and together comprise three of the four strewn fields. Besides the evidence from Barbados and DSDP 612, the geographic patterns of distribution (Fig 3) also strongly support this. The new find of microtektites in ODP 689B on the Maud Rise of the Weddell Sea at 64° 31.009' S, 03° 05.996' E (Glass & Koeberl 1999), though extending the strewn field by a remarkable amount, still fits onto the extension of the Barbados ray of the pattern of non-homogeneity suggested by Koeberl (1989)

The following conclusions can be drawn concerning the Australasian strewn field

1) There should be source structure, once a crater, for the Australasian strewn field, since all the other three strewn fields have established source craters. A number of possible sites have been investigated or suggested (for example under the Mekong delta (Stauffer 1978), Tonle Sap, Cambodia (Hartung 1990), in Laos (Schnetzler & McHone 1996), offshore from Vietnam (Schnetzler *et al.* 1988) and somewhere in China (McCall 1997), without a positive result.
2) This crater should be *ca* 0.77 Ma old, consistent with the radiometric age of the tektites.

3) The radiometric age should indicate the age of fall to Earth of the tektites which is inseparable from the age of the source structure, being separated only by the very brief period of sub-orbital flight.

4) The suggestion that microtektites are not related to the same event as the Australasian tektites seems difficult if not impossible to maintain in the light of the North American and Ivory Coast evidence, similarity of geochemical composition and isotopic signatures (for example, Glass 1990; Shaw & Wasserburg 1982), not to speak of the geographical patterns and age relations in all three strewn fields other than the Australasian (and indeed the geographical pattern in the Australasian strewn field itself and the recovery of an ablated tektite from the middle of the Indian Ocean amidst a cluster of microtektite recoveries (Glass *et al.* 1996).

5) Lack of recovery of tektites from a stratigraphic formation does not necessarily mean that it is older than the arrival of the tektites.

6) Tektites have been reworked by geological processes in all the other three fields and there is evidence for recent reworking in Australia.

7) The lack of microtektites in recent soils is not inconsistent with the radiometric age being the age of fall to Earth.

8) There is some evidence from the Bow River in the north of Western Australia of tektites in a formation of much older stratigraphic age than that suggested from Lake Torrens, although the method used cannot precisely date the tektite-bearing gravels.

9) The evidence of Glass & Wu (1992) that no microtektite productivity occurred around Australia at 20 000 years or less strongly indicates that there was no late Pleistocene tektite event in Australia.

Having said all this, the study of Lovering *et al.* (1972) is extremely difficult to fault, and if the conclusion of these authors and Mason (personal communication) are incorrect, then we have to accept that extremely well preserved flanged button ablated tektites can undergo several cycles of geological redistribution over a period of three quarters of a million years, while others have become abraded, fragmented and even may have lost all traces of ablation, and that somehow, some have managed to escape such degradation and preserve the delicate flange. The Port Campbell australites are the best preserved as a group, yet they, like the equally well-preserved examples from Lake Torrens and Western and Central Australia, were recovered alongside degraded, fragmented and manifestly transported forms. Some flanged buttons from Port Campbell, Lake Torrens and Western and Central Australia are illustrated (Fig 4). An example of partial preservation of the flange, with the scar where the remainder detached; a 'core' in which only the circumferential detachment scar is left; and a highly degraded example, all three from Finke, Northern Territory (Cleverly 1988), are illustrated in Fig 5. The complexities of behaviour of australites in ablating flight were well illustrated by Cleverly (1987); complete or partial parting of the stress shell commonly occurred, preservation of stress shell and flange being exceptional, and after fall to Earth, there was a wide disparity in the activity of agents of geological degradation on australites, even from the same site (in this case Ravensthorpe, Western Australia). We have to accept that the almost pristine ablated forms illustrated in Fig 4 have somehow survived for 0.77 Ma and escaped the degradation that is evident for the last two illustrated in Fig 5, incredible though this may be.

The author believes that one has to accept, after considering all the weighty indirect evidence listed above, that some flanged button australites were able to pass through several cycles of geologic redistribution over a period of 0.77 Ma without severe modification by erosive agencies. Those that survived in Victoria, South Australia, Western Australia and the Northern Territory were probably a minority; this is certainly true of Western Australia. The flanged form must, if this is true, be more resistent to abrasive degradation than we have hitherto believed.

We also have to accept that in Victoria, South Australia, Western Australia and Central Australia, there must have been older, tektite-bearing geological formations, of which we have no knowledge (despite the evidence advanced against this from Lake Torrens advanced by Chalmers *et al.* 1979). We will almost certainly never know anything of the "dark ages", the intervening stages of redistribution and lodgement in older formations than those from which the tektites are recovered, unless, by chance, a concentration of tektites is found in such an older formation (as may have occurred at the Bow River). The geological record is a very imperfect data-base and has a bias towards what we can now see at the surface, despite the contribution of drill cores. Tektites may have been very dispersed in the older formations and undergone concentration in the younger recovery formations. We will probably never know how these ablated forms came to be preserved, though some form of protection such as entrapment in clay over much of their history could be invoked. A clue might be found in the fact that some of Baker's Port Campbell collection reportedly comes from a clay deposit.

If we accept that radiometric age equals age of fall to Earth, then we have to discount the evidence of specific gravity and chemical variation advanced by Chalmers *et al.* (1979) to show that the site of recovery is very close to the site of fall, a major step but one that is unavoidable. The preference for this solution owes something to "Occam's razor, that entities are not to be multiplied without necessity." The author believes that this must be the correct solution, remarkable though it is, and it is not one of an age paradox requiring two distinct arrival events; the requirement to explain the apparent age paradox lies in accepting that these apparently fragile objects (ablated flanged tektites) have survived on Earth for a period of 0.77 Ma, and that there must have been stages in their passage from fall to their present find sites of which we have no evidence or knowledge. Otherwise, if we accept the alternative solution, then we are left with a pattern of microtektites recovered from the ocean surrounding Australia, coincidentally of the same stratigraphic age as the derived radiometric age of the australites recovered from the continent, but with no equivalent tektites on the continent. Surely, this is a highly improbable coincidence? We are also left with the

Figure 4. Examples of remarkable preservation of flanged button ablated australites. **Top row**: from Port Campbell, posterior and side view (Photographs: Baker 1963, magnification x 2.4): from the Myrtle Springs interdune corridors (Photograph: Lovering *et al.* 1972, maximum dimension 10 mm). **Second** and **third row**: from Gindalbie and Menangina Stations, Western Australia (Photographs: WH Cleverly 1994, maximum dimensions about 20 mm). **Bottom row**: from Finke, Northern Territory (photographs: WH Cleverly 1988 maximum dimensions about 20 mm)

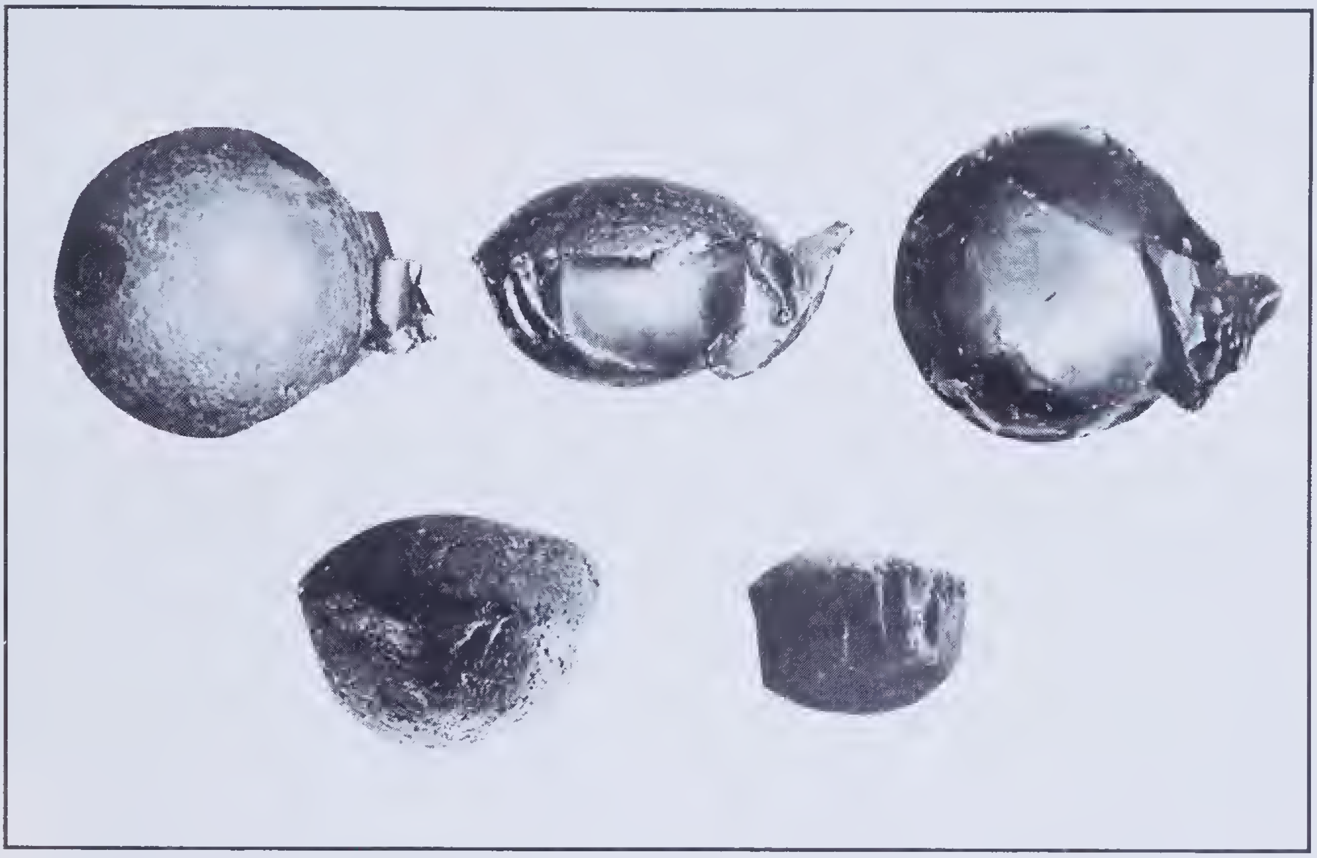

Figure 5. Three tektites from the vicinity of Finke, Northern Territory, Australia: (Photographs: WH Cleverly 1988). **Top row**: with partial flange preserved, showing the equatorial flaked zone where it has been partly lost, three views (maximum dimension 35.6 mm). **Bottom row**, right: without any flange, but showing the equatorial flaked zone where the flange has separated (maximum dimension 35.3 mm): left; without any flange, much more degraded by terrestrial transport and abrasion (maximum dimension 17.5.mm)

radiometric age being the age of ejection from impact structures and return to Earth in the three other strewn fields, but not in Australia!

An additional question arises; if australites could survive for 0.77 Ma on Earth as flanged buttons, why are no ablated forms found among the south-east Asian recoveries? Though the climate in south-east Asia is quite different to that of Australia and would have favoured quicker degradation, a few ablated forms surely should have survived among the thousands of tektites from Indochina? The probable answer to this question, considering that the furthest north that ablated tektites have been described from the Australasian strewn field is Java and Flores, Negros Island, Philippines, and the Central Indian Ocean, is that, although the source is not known, the northern recoveries are proximal to the source, and their trajectories did not involve exit from and re-entry to the atmosphere. Thus, only primary splash forms have been recorded.

Shoemaker & Uhlherr (1999) add significantly to the Port Campbell picture in showing that australites, including complete aerodynamically ablated forms, occur in ferruginous sandstone clasts within the late Pleistocene-Holocene Sturgess Sand formation, reworked from the underlying Pliocene-Pleistocene Hanson Plain Sand (and weakly cemented sandstone), in which australites are also found in channel deposits. They concluded that as australites occur in strata older than the late Pleistocene-Holocene Sturgess Sand, there is no longer any conflict in the Port Campbell area between the apparent stratigraphic age of the tektites and the middle Pleistocene ages obtained by chronometric methods. These authors also noted the presence of australites together with mollusc shells in aboriginal middens, evidence that Aborigines have transported tektites.

Koeberl (1994) observed "The hydra of the so-called age paradox occasionally rears its heads and needs to be addressed at least briefly......" Surely, now, we can say that the "hydra" has at last been given the coup-de-grace?

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